

Exploration of the Gas Giants
and the Ice Giants,
Space Missions to Jupiter,
Saturn, Uranus, and Neptune

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Introduction

This book will discuss the exploration of the four largest planets in our solar system, all located beyond the orbit of Mars. The first two, Jupiter and Saturn are termed the Gas Giants, and the next two, Neptune and Uranus, are the Ice Giants.

Each has an extensive set of moons, and a ring system. Each is unique in many ways. They have been explored extensively, and more information is gained every day about their composition and behavior. It's thought that some of the larger moons might harbor life beneath an icy crust. They could also provide a landing site and outpost for humans. There is a lot more to learn about these systems, and how the planets and the solar system in general formed, and behaves. Comparing this information with exo-solar systems, that we have just begun to observe, will tell us if we are unique or run-of-the-mill in the big scheme of things. We may also learn to avoid system-wide disasters and extinction events.

Author

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A note on Units

I am fairly conversant in both English and Metric units (what is

the metric equivalent of furlongs per fortnight?). Metric (SI) is mandated for NASA usage now, for interchangeability with our partner space faring nations. When a lot of the legacy flights discussed here were flown, English units were the norm. I have tried to keep the units comparable to the mission at the time. Conversions are easy enough, but units conversion is a source of error. It's not what you know about units and measurement, its how you think. And, I still think English units (even the English use Metric now), and convert in my head or on my phone.

For scientific/engineering work, the Metric system is well thought out. For artisans, the English system served well, as most units were divided by 2. Which is easy. Fold the cloth. Hopefully, when we are all taught Metric first, some one will still remember the conversions. You just need a good slide rule....

Planetary Science Decadal Survey

The U.S. National Research Council produces the decadal survey for NASA and NSF, among others. It defines key questions for the next ten years, and defines missions that are then prioritized. Its an exploration roadmap for space. It is readily downloadable as a (not free) .PDF document. The link is in the Resources section of this book.

NASA Plans ahead for Space Exploration by the Decadal Surveys for Astrophysics, Heliophysics, and Planetary Science. This brings together the ideas of the science community to form a consensus on how to proceed. This is NASA's Science Mission Directorate reaching out to the Science community for direction. The latest report, available from the Planetary Society, is “Vision and Voyages for Planetary Science in the Decade 2013-2022 “ This report features Cubesat technology prominently. The report expresses the consensus of the Science community, and takes more than a year to produce. There is no guarantee that any of the projects will be funded.

Exploration

A lot of exploration takes place from Earth-based observatories, in the optical and radio frequencies. These observatories have to look through the atmosphere, which is blurry. But, the method has been used for hundreds of years, and many major discoveries have been made. Another giant leap was made when photography replaced direct observation through the telescopes. Wouldn't it be better if we could put the telescope in space? Why, yes, it would. Many observatory satellites have been placed in orbit, the best known being the Hubble Space Telescope.

NASA's Great Observatory's Program includes telescopes in Earth orbit, HST for visible light, the Compton Gamma Ray Observatory, the Chandra X-ray observatory, and the Spitzer Space Telescope, operating in the infrared part of the spectrum. A forerunner of these missions was the 1966 Orbiting Astronomical Observatory, which the author worked on (the spacecraft and operations side).

HST

The Hubble Space Telescope was placed in orbit by the Space Shuttle in 1990. It is still operating as of this writing. It is managed by the Goddard Space Flight Center, and the data goes to the Space Telescope Science Institute on the Johns Hopkins University Campus in Baltimore, MD. The concept was introduced in a paper in 1946, well before the “space age.”

Hubble has a 2.4 meter mirror with corrective optics installed in orbit by astronauts from the Space Shuttle. This was due to a flaw in the mirror, not noticed until after launch. The update took five Shuttle Missions, and also included change-out of some of the instruments. The onboard computers were updated, and the original tape recorder was replaced by a solid state unit. All six gyroscopes were replaced, as well as the solar panels. This illustrated the versatility of repairs in space.

Hubble currently downlinks about 140 gigabytes of observation data weekly. It is used in the search for Exo-planets, and other star systems.

Challenges

Once we leave the vicinity of our home planet, conditions deteriorate quickly. The major issue is radiation, since we are outside of the safety of the trapped radiation belts, which provide some protection. This is the major challenge, but there are many known ways to mitigate this problem. Then, there is the thermal problem. We're going somewhere that's hotter (sun-ward), or colder. A big issue is the mission duration. It takes years to get to some of the outer planets, and even if the system is powered off, there can be events that will cause it not to wake up. Missions outside the rather friendly environment of near-Earth face additional challenges that must be addressed.

At the same time, communications becomes more difficult, and achievable data rates go down. The spacecraft might find itself on the other side of the Sun, from Earth, and communications would not be possible. JPL is exploring laser communication links for long distances.

These are all solvable problems, but require additional engineering analysis, and the development of new technologies.

Communications

NASA's Deep Space Network consists of three sites spaced around our planet. It supports deep space missions for NASA and other entities. It is managed by the Jet Propulsion Lab (JPL) in Pasadena, California. The nearest station to JPL is at Goldstone, in the desert to the east. Two other stations, in Spain and Australia are spaced about 120 degrees apart on the globe from Goldstone. The DSN started operations in the 1960's, with teletype communications with the Pasadena facility. The DSN is heavily oversubscribed, supporting numerous deep space missions.

Several approaches to communication with spacecraft at a large distance from Earth, and examining other planets have been defined. The Interplanetary Internet implements a Bundle Protocol to address large and variable delays. Normal IP traffic assumes a seamless, end-to-end, available data path, without worrying about the physical mechanism. The Bundle protocol addresses the cases of high probability of errors, and disconnections. This protocol was tested in communication with an Earth orbiting satellite in 2008.

As we get farther from Earth, we have to get clever with communications. With the New Horizons spacecraft at Pluto it took more than 16 months to transmit all the data back.

The Deep Space Net

NASA provides telemetry and command support for its own Cubesat missions, using its existing Near Earth Network and Space Network (TDRSS). The agency is planning to support lunar, L1/L2, and Mars missions, which is a challenge due to distance, the small Cubesat antenna, and limited power budget.

JPL estimates an interplanetary laser communications package is at TRL level 6 (2012), and a package to fit a 1U Cubesat would be around 1.8 kg and require 5 watts of power.

Interplanetary Internet

Communications between planets in our solar system involves long distances, and significant delay. New protocols are needed to address the long delay times, and error sources.

A concept called the Interplanetary Internet uses a store-and-forward node in orbit around a planet (initially, Mars) that burst-transmits data back to Earth during available communications windows. At certain times, when the geometry is right, the Mars bound traffic might encounter significant interference. Mars surface craft communicate to Orbiters, which relay the transmissions to Earth. This allows for a lower wattage transmitter

on the surface vehicle. Mars does not (yet) have the full infrastructure that is currently in place around the Earth – a network of navigation, weather, and communications satellites.

For satellites in near Earth orbit, protocols based on the cellular terrestrial network can be used, because the delays are small. In fact, the International Space Station is a node on the Internet. By the time you get to the moon, it takes about a second and a quarter for electromagnetic energy to traverse the round-trip distance. Delay tolerant protocols were developed for mobile terrestrial communication, but break down in very long delay situations.

We have a good communications model and a lot of experience in Internet communications. One of the first implementations for space used a File Transfer Protocol (FTP) running over the CCSDS space communications protocol in 1996.

The formalized Interplanetary Internet evolved from a study at JPL, lead by Internet pioneer Vint Cerf, and Adrian Hook, from the CCSDS group. The concepts evolved to address very long delay and variable delay in communications links. For example, the Earth to Mars delay varies depending on where each planet is located in its orbit around the Sun.

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NASA's Goddard Space Flight Center in Greenbelt, Maryland, has been the hub of the space data network since the beginning. In the Apollo era, a world-wide system of ground stations providing continuous coverage was not yet in existence. NASA supplemented their ground stations with a series of tracking ships, to fill in coverage gaps. All data came to the basement of the Operations Building, 14, at Greenbelt. It was then routed upstairs

to satellite control centers, and to Houston or Marshall for Manned flights. For its interplanetary missions, JPL maintained the Deep Space Network, a set of three very large antennas spaced around the world. During launch and near Earth operations, these were supplemented by NASA's world-wide set of tracking stations for Earth orbiting satellites.

Power

Out to the orbit of Jupiter, solar cells work well for exploration missions. Beyond that, a large spacecraft will not get enough electrical power. A traditional approach has been to use RTG's – Radioisotope Thermoelectric Generators. These work by using thermocouples to convert the heat from the decay of a radioactive material into electricity. No moving parts. There is a safety concern during launch that the radioactive material could get scattered in an explosion. The units are good for a few hundred watts of power, for decades.

A common radioactive source is plutonium-238, with a half-life of 88 years. RTG's have been used in space since 1961.

Due to advances in solar cell efficiency, the Juno mission to Jupiter successfully used them for power, in lieu of a RTG. The Voyager spacecraft, in interstellar space, continue to transmit back data, and will have enough power from their RTG's for a century or so. Smaller radioactive heater units are also used for long distance missions.

Radiation Environment

The radiation environment past Mars is less influenced by the Sun, then by Cosmic rays. Of course, Jupiter, with its strong magnetic field, has managed to accumulate significant trapped radiation belts, from its interaction with the solar wind. In transit, the main radiation issue is energetic cosmic rays.

Energetic protons are also a problem, as are gamma rays. These

can cause single-event upsets in electronics, as well as cell damage to humans. Cosmic radiation originates outside the solar system. It consists of high energy protons, and atomic nuclei. It is postulated that Cosmic rays originate from stars' supernova explosions.

Exploring the Gas Giants

The Gas giants are the planets Jupiter, and Saturn. The Ice Giants are Uranus and Neptune. These are the responsibility of the Jet Propulsion Laboratory. These each have extensive ring and moon systems that have been imaged, but are just beginning to be explored.

The Gas Giants are two large planets, beyond the orbit of Mars. They consist mostly of the gases hydrogen and helium. At depth, they consist of liquid metallic hydrogen. There may be a core of solid hydrogen, or a rocky material. It is possible these elements exist as a liquid at extreme depths. Essentially, a gas giant planet is a failed star. The nuclear fusion process did not get started.

The gas giants have a prominent cloud system in the upper atmosphere. Extrasolar Gas giants have been discovered orbiting other stars than our Sun.

Trojan Asteroids are in the same orbit as a primary, in front and behind (at the 4th and 5th Lagrange points).

Pioneer 10 was the first mission to Jupiter, followed by Pioneer-11 in 1973, and, as of this writing, there have been 8 total. Jupiter has a very high trapped radiation environment. The moons are mostly all different, and some are thought to be capable of hosting life, as we know it. The moon Io has volcanic activity, as seen by the current Juno mission. It imaged the volcano Surt in December of 2017 at the southern pole. It used its Jovian Infrared Auroral Mapper (JIRAM) instrument

Europa has water ice on the surface. Europa is considered “one of

the most promising extraterrestrial habitable environments in our solar system” according to the most recent Planetary Society's Decadal Survey. A proposed mission, ExCSITE, would provide characterization of the surface properties. One option is multiple Cubesats.

NASA is looking at the Explorer CubeSat for Student Involvement in Travels to Europa (ExCSITE) Mission. This involves multiple Cubesat imagers and impactors.

If you're clever, you can take advantage of planetary alignments to allow visiting multiple planets on the same mission. At the least, you can take advantage of a “gravity assist” from a planet to reduce fuel requirements for visiting additional targets. The Sun is also used for gravity assists.

The Voyager missions were originally termed the “Grand Tour” and were to have visited Mars, Jupiter, and Saturn, with possibly some of the outer planets as well. Proposed in 1966, the mission was called MJS-77. It was to be launched in 1977, to take advantage of a once in 176 years opportunity, because of the planetary alignments. Budget constraints caused the mission to refocus on Jupiter and Saturn alone. It was renamed Voyager. The author worked on this mission. There were two spacecraft. As I type, Voyager I is in Interstellar Space, having left our solar system, and Voyager-2 is technically in the heliosheath, where the solar winds begins to be slowed by interstellar gas. The current mission duration is 40 years. They are 142 and 117 AU from Earth. The one-way light time is 14 and 16 hours. Some instruments are still functional, and the Voyagers are returning data about conditions in interstellar space, at a data rate of 160 bits per second.

Jupiter

Jupiter has 67 known moons, (Stop the presses. The International Astronomical Union has just announced the discovery of 12

previously unknown moons of Jupiter, by an observatory high in the Andes in Chile. Only one has been named so far, Valetudo, a great-granddaughter of Jupiter). and 600,000 known Trojans. The Trojans tend to congregate at the L4 (Greek Camp) and trailing L5 (Trojan Camp) positions. The largest has a diameter of several hundred kilometers. The Trojan 617 Patroclus is part of a binary asteroid pair. The Lucy Mission in 2021 will specifically study the Trojans.

The International Astronomical Union is in charge of name selection for planets, moons, asteroids, comets, and such. Generally, the discoverer submits their suggestion, which is usually confirmed.

The one-way light time for Jupiter to Earth is 33-53 minutes. Jupiter it does not have a discernible solid surface. It rotates at different speeds at different latitudes, or, more accurately, the observable clouds rotate at different rates. The polar and equatorial diameters differ by some 6,000 miles, due to the rotation, and the fluid nature of the planet. If things had gone differently earlier in Jupiter's formation, it may have become a small star.

The Galileo spacecraft entered Jupiter orbit in 1995, and remained operational until 2003. It returned data on the planet and the four Galilean moons. Three of the moons have thin atmospheres, and may have liquid water. Galileo was in the right place at the right time to see the comet Showmaker-Levy-9 enter the Jovian atmosphere. It also launched an atmospheric probe. It also imaged the four Galilean moons (Io, Europa, Ganymede, and Callisto), and found thin atmospheres on three. Galileo is credited with discovering a magnetic field around Ganymede. The moon Ganymede is actually larger than the planet Mercury.

Jupiter has a very harsh radiation environment of trapped charged particles, due to its large magnetic field. These are similar to Earth's Van Allen Belts, but much more intense. The

magnetosphere rotates with the planet, and the side facing the Sun is flattened, due to the Solar wind. Jupiter is very noisy, producing radio energy in three distinct bands. The moon Io, passing through the Jovian magnetic field, can be charged to an estimated 4×10^5 volts. At certain positions, an electric current flows between Jupiter and Io, in the range of millions of amps. This is probably the source for the observed radio wave emissions.

The sixty-nine known moons of Jupiter are about as diverse as then can be. The four large Galilean Moons were discovered in 1610. They would be classified as planets if Jupiter hadn't captured them. The number of Jovian moons continues to grow, with better telescopes, and more deep space missions. Their orbits are as diverse as their composition, some orbiting retrograde. The orbital periods can vary from hours to three Earth years. The moon Dia, discovered in 2000, is now missing. There may have been a collision.

The Jovian Ring System was first spotted by Voyager-1 in 1979, although data from Pioneer 11 in 1975 hinted at their existence. Further observations from Voyager-2 and Galileo provided most of our knowledge about these features. The ring systems of Saturn and Uranus had been discovered earlier. They have been investigated by the Galileo orbiter, and they consist mostly of dust. There are four rings, separated by gaps. Shepherding moons orbit the planet at the inner and outer ring edge, and keep the dust particles well-organized. Prometheus is on the side toward the planet, and herds the F ring. Pandora is the outer shepherd moon

The material in the rings is mostly dust, and is not very reflective. There are considered to be 4 concentric rings.

The Hubble Space Telescope discovered that one satellite of Jupiter, Ganymede, has a large saltwater ocean, under an ice crust. This is now thought to be the best current hope for finding life on another planet.

Pioneer-10, in 1973, was the first spacecraft to visit Jupiter. There have been eight additional missions, to this writing. All have been NASA missions. There were seven fly-bys, that went on to other interesting places, and two dedicated missions. Following Pioneer-10, Pioneer-11 went to the big planet. These missions took the first close-up pictures of the planet, and discovered the Jovian magnetosphere. Pioneer-11 was the first to image the Great Red spot, and the polar regions. The Great Red Spot has been around since the 17th Century at least. The astronomer Cassini sketched it, but did not mention the color. It is a stable anticyclonic (counter-clockwise) storm. Hubble has found two adjacent red spots. The main storm goes up to 8 kilometers above the cloud tops. The Great Red spot could hold Earth. There is also a Little Red Spot in the southern hemisphere. Whatever it is, it floats in the Jovian atmosphere.

The magnetosphere of Jupiter is much stronger than that of Earth, by a factor of 14. It is probably an artefact of a liquid metallic hydrogen core at Jupiter's center. It extends seven million kilometers towards the Sun, and almost to the orbit of Saturn. Whereas the Earth's magnetosphere is shaped by the solar wind, Jupiter's is shaped by its moon, Io's plasma. The Jovian magnetosphere is torus shaped, and rotates with the planet. The magnetosphere is a particle accelerator, using the intense magnetic field to drive the particles to high velocities. The magnetic field itself is caused by the rotation of Jupiter's core of liquid metallic hydrogen. Volcanic activity on the moon Io releases compounds of sulphur. These are ionized by solar ultraviolet radiation, and form into a plasma torus, and ring current around Jupiter. This in turn interacts with the Jovian magnetic field.

Voyager-1 and Voyager-2 passed by in 1979, and went on to image Saturn, Uranus, and Neptune. Their particular alignment at this time allowed this. Voyager discoveries included volcanic activity on the moon Io, and water ice on Europa. They discovered an additional moon of Jupiter, and imaged the eruption of nine volcanoes.

Ulysses visited Jupiter in 1992, and 2004. It used Jupiter's gravity to move out of the ecliptic plane, and returned to the Sun, achieving a polar orbit.

The Cassini Mission supplied detailed pictures of the Jovian atmosphere on its way to its primary target, Saturn. It returned valuable data about Jupiter's circulation, not noticeable from Earth. It also used Jupiter for a gravity assist.

New Horizons went by in 2006, on its way to Pluto and beyond, and took detailed data. It recorded an infrared image of the moon Callisto. It did detailed observations of the moon Io's active volcanoes. The plumes contain tons of material, and extend out hundreds of kilometers.

New Horizons used a gravity assist manoeuvre from Jupiter, shortening its travel time to Pluto by three years.

In total, the New Horizons observed the Jupiter system for four months. Primary observation goals were atmospheric conditions and cloud structure.

The Juno mission launched in 2011, and arrived after 5 years of travel. It was placed in Jupiter elliptical polar orbit for 5 years, and the plan was to de-orbit into Jupiter in February 2018 to prevent biological contamination. It is as of this writing on extended mission until 2021. It is still collecting good data on Jupiter's lightning and jet streams.

The orbit was chosen to minimize contact with Jupiter's intense trapped radiation belts. Its sensitive electronics are housed in "the Juno Radiation vault," with 1cm titanium walls. It will have available to it some 420 watts of power, from the solar arrays.

The spacecraft weighs over 1,500 kg. It uses 3 solar panels of 2.7 x 8.9 meters long. These will be exposed to about 4% of the sunlight at Earth. It left Florida on an Atlas-V vehicle. The perijove, or closest distance to the planet was planned to be 4,200

km. The highest altitude at apoove is 8.1 million kilometers.

It included infrared and microwave instruments to measure the thermal radiation from Jupiter's atmosphere, being particularly interested in convection currents. It's data will be used to measure the water in Jupiter's atmosphere, measure atmospheric temperature and composition, and track cloud motions. The mission will also map Jupiter's magnetic and gravity fields. It is expected to probe the magnetosphere in the polar regions and observe the auroras. Juno is in polar orbit.

Communications supported 50 Mbps of data. The spacecraft will be constrained to 40 Mbytes of camera data per 11-day orbit period.

Juno uses a bi-propellant propulsion system for orbit insertion and a mono-propellant system for attitude control.) The mission is expected to continue until 2021.

Jupiter's Magnetic field is 20,000 times that of Earth. This would allow for the use of a conductive tether to generate electricity. The cost is reducing the orbital kinetic energy, which would require periodic reboots.

ESA will launch the Jupiter Icy Moon Explorer (JUICE) mission in 2022 with a possible Ganymede lander.

The Indian Space Research Organization is also planning a mission to Jupiter in the 2022-23 timeframe.

Recently, a massive cyclone was discovered on Jupiter, by the Juno spacecraft. Previously, upon arrival, Juno discovered nine cyclones in the northern hemisphere and 6 in the south. The new guy has wind speeds of some 225 miles per hour. If everything continues to work well, Juno will collect data until 2021.

Saturn

Saturn and its 82 known moons has a one-way light time to Earth around 1.4 hours. Saturn is about one-third the mass of Jupiter, and has been visited by spacecraft four times. The first was a flyby by Pioneer-11 in 1979. This showed the temperature of the planet was 250 degrees K. Pioneer 11 visited in a flyby in 1979.

Voyager-1 visited in a 1980 flyby. It conducted a close flyby of the moon Titan to study its atmosphere. It is, unfortunately, opaque in visible light. We do know it rains methane. Voyager-2 swung by a year later, and data showed changes in the rings since its sister mission visited the year before. Temperature and pressure profiles of the atmosphere were gathered. Saturn's temperature was measured at 70 degrees above absolute zero at the top of the clouds, and -130C near the surface. The flybys discovered additional moons, and small gaps in the rings.

ESA's Cassini was the fourth spacecraft to study Saturn, which has rings, although smaller than Jupiter. The rings were confirmed by the Voyager spacecraft in the 1980's. Cassini entered into Saturnian orbit, and returned much valuable data. At the end of mission, it was de-orbited into Saturn, and burned on entry into the atmosphere. This was to preclude any biological contamination from Earth. The film of it entering the atmosphere was nominated for an Emmy award. It has also collected data on the Saturnian moons Titan, Enceladus, Mimas, Tethys, Dione, Rhea, Iapetus, and Helene. The one-way communications time varies from 68-84 minutes.

Twenty of the moons were added in 2019, thrusting Saturn ahead of Jupiter for having the most moons. Not all have been named. We're starting to run out of Roman and Greek gods, so the new moons will be from the Norse, Gallic, and Inuit groups. Seventeen of them are in retrograde orbits; they move opposite of Saturn's rotation. The discovery is credited to the Subaru telescope in Hawaii.

Enceladus has definite organic compounds, nitrogen and oxygen based, in plumes.

Things are strange in the Saturnian system. Cassini observed a hurricane in 2006 on the planet's south pole. It appears to be stationary, 5,000 miles (8,300 km) across, 40 miles (67 km) high, with winds of 350 mph (560 kph). The large moon Titan has lakes of a liquid hydrocarbon, with possible seas of methane and ethane. The Cassini mission was responsible for the discovery of seven new moons of Saturn. It conducted a close flyby of the moon Phoebe, and two fly-bys of Titan. Phoebe has a retrograde orbit. Cassini launched the Huygens probe onto the moon Titan. It landed, and continued to supply data. Cassini was also responsible for discovery of another ring, as well as finding lakes of hydrocarbons near the north pole of Titan. These turned out to be larger than first thought, and we renamed seas. Keeping busy, Cassini discovered four additional moons in 2009. Lasting beyond its primary mission of completing 74 orbits, the spacecraft went into extended missions, operating until 2017, when it entered the Saturnian atmosphere.

The rings of Saturn are the most extensive, larger than Jupiter's. They consist mostly of water ice. The astronomer Huygens was the first to observe and describe them in 1655, subsequently getting a spacecraft mission named after him. There are two gaps in the rings, caused by moons orbiting at that distance from the planet. Orbital resonance by Saturn's moons cause other gaps. The outermost moon, Phoebe, is tilted at 27 degrees to the others, and orbits the planet in retrograde, opposite of the other rings and satellites. The Cassini division (named after its discoverer) separates the inner B ring, and the outer A ring. There are twelve known rings.

The moon Enceladus was observed to exchange plasma waves with the planet, and the ring system. Cassini's Radio Plasma Wave Science (RPWS) instrument recorded intense plasma waves during one of its close encounters. The moon is within the

Saturnian magnetic field. It is also geologically active, sending out plumes of ionized water.

Cassini observed a massive storm on Saturn, the great white spot, that recurs every 30 years. The storm, larger than the red one on Jupiter, exhibited a discharge that spiked the temperature 150 degrees. At the same time, Earth observations showed a large increase in atmospheric ethylene gas. It also discovered large lakes or seas of hydrocarbons near the planet's north pole.

Cassini discovered a possible atmosphere on the moon Enceladus, along with with ionized water vapor, and ice geysers. Many of the Saturnian moons are in tidal lock with their mother planet. Being so close to its giant neighbor Jupiter affects the Saturnian system.

Cassini cost \$3 billion (\$10⁹) and couldn't get close enough to Saturn's rings because of the ice particles. One hit could cancel the mission. Imagine instead a Cassini-size spacecraft at a safe distance, deploying swarms of hundreds of Cubesats.

Just recently, as this book was being published, NASA announced 20 previously unknown moons. The total is now 82. They are all small, which explains why we didn't know about them yet. Three orbit in a prograde (same as Saturn's rotation) manner, while 17 are retrograde. They have yet to be named, but NASA has a process.

Exploring the Ice Giants

Uranus and Neptune differ from Jupiter and Saturn in that they have heavier volatile substances in their atmosphere, and are now referred to as ice giants. Their atmospheres are known to contain water, ammonia, and methane ice.

Uranus

Interestingly, Uranus' rotation axis is tilted into the plane of its

orbit around the Sun. Seasonal changes and weather have been observed. The Voyager-2 mission imaged Uranus on its way from Jupiter, and out of the solar system. Atmospheric wind speeds are known to approach 900 kilometers per hour. Its orbital period is 84 Earth years. It receives about $1/400^{\text{th}}$ of the light that the Earth does from the Sun, so solar power is not a viable choice. In addition, the moons rotate in the plane normal to the velocity vector. Uranus is sideways, or lying on its side, compared to all the other planets. Its spin axis is 98 degrees out of the orbital plane with the Sun. Earth is tilted $23 \frac{1}{2}$ degree. Speculation is that something bumped it hard enough to cause that extreme tilt. Current thinking is, two collisions. With what?

Because of the strange orientation of the planet's rotation axis, during the solstice, one side of the planet faces the Sun continuously, and the other faces deep space. Each pole gets 42 years of direct (though weak) sunlight, and 42 years of darkness. In spite of this, the equator is the hottest region. At this writing, the planet is in its autumnal equinox.

The moons of Uranus are all named for characters from Shakespeare or Alexander Pope. There are thirteen inner moons, 5 major ones, and nine irregular moons. The inner moons have the same properties as the ring system. The major moons show signs of volcanism. The irregular ones have strongly inclined orbits, some retrograde. The major moons are roughly in the plane of the planet's equator. Uranus has a magnetic field.

The ring system was not discovered until 1977, since they are dark and faint. Nine were known until the Voyager visit, when an additional two were discovered. The Hubble Space Telescope found an additional 2.

Uranus was visited by Voyager-2 in 1986, after the spacecraft went by Jupiter and Saturn. It discovered ten moons, and two additional rings in the known ring system. Voyager also captured some images of the Uranian moon Umbriel, and discovered a

magnetic field. Since the planet is tipped 90 degrees, the magnetotail is cork-screwed. The ring system is fundamentally different from that of Jupiter or Saturn. Voyager-2 is the only spacecraft to date to visit the planet, as it continued its grand tour of the outer planets.

Uranus has a strange predominately water-ammonia ocean, which is electrically conductive. A future planned mission is the Uranus Orbiter and Probe. It was defined in the Decadal Survey for 2013-2022. There is a planned launch in 2030, with Uranus orbit insertion in 2041. The mission is named Oceanus. (Origins and Composition of the Exoplanet Analog Uranus System). A Jupiter gravity assist will be used. RTG's will be used, as the sunlight at that distance will only be about 0.3% of Earth normal.

Neptune

Neptune has 14 known moons, and 18 known Trojans. It's one-way light time is around 4.3 hours. It was predicted to exist, based on perturbations of Uranus, which kept deviating from its calculated position. By the Titius-Bode law, the perturber had to be at 39 AU. It was discovered in 1846. Seventeen days later, the moon Triton was discovered, in a polar orbit.

The Titus-Bode law is a hypothesis that planets would be spaced twice as far from the Sun as the previous. The proof of the law is not known, but it did locate Uranus and Ceres in the right place, but failed for Neptune. The four major satellites have as regular, non-Titus-Bode spacing. Same for the big moons of Uranus. There has not been enough data to try to apply the rule to exoplanets as of this time.

Neptune was visited by the Voyager-2 mission in 1989, when six moons were discovered. That is the extent of close-up observations of the planet. Neptune has rings, like Jupiter and Saturn, and a Great Dark Spot in the Southern hemisphere. It's largest moon, Triton, has geysers and polar caps. The moon Triton has an interesting retrograde orbit – it goes in a different direction

than the other moons. Triton's surface is mostly frozen nitrogen, and is geologically active. It is speculated that Triton has a subterranean ocean. The moon Proteus is an ellipsoid, not a sphere. The atmosphere is mostly hydrogen and helium, with some hydrocarbons. It also has water, ammonia, and methane ice. Neptune also has a significant magnetosphere, that interacts with the solar wind.

The latest moon to be discovered was Hippocamp, from HST images. It was too small to be observed by the Voyager. It was formally named in February of 2019. The previous discovery was Psamathe, in 2003.

Hippocamp's orbital period is about 22 ½ (Earth) hours. It is located between the moons Larissa and Proteus.

Now that Pluto has been downgraded to minor planet status, Neptune is the farthest planet in our solar system from the Sun. It is at an average distance from the Sun of 30 AU, and orbits every 165 years. It was found by mathematical prediction, as it is not visible without a good telescope. Something was perturbing the orbit of Uranus. The intruder was predicted in a certain location, and was then observed by telescope in 1846. In Galileo's notes from 1612-13, there are points that correspond to the position of Neptune. His telescope was just not quite good enough to resolve it. He mentioned that the object moved relative to the "fixed" stars.

By spectroscopic analysis, the atmosphere is mostly of hydrogen and helium, with some hydrocarbons, and trace amounts of nitrogen. At the equator, methane, ethane, and acetylene are found. It has a blue color, due to methane in the atmosphere. It's atmosphere has visible weather patterns, with winds of up to 1,300 mph. Neptune has a magnetosphere, with a magnetic field tilted some 47 degrees from the spin axis. Neptune has extreme weather, with winds reaching supersonic speeds.

Centaurs

The Centaurs are icy minor planets between Jupiter and Neptune. A Centaur is a type of dwarf planet, orbiting the Sun. They are not quite making the cut to “real planet.” There are 406 known. They have unstable orbits that intersect those of the gas giants. The largest known, Chariklo, has a ring system. These have not been photographed from a close position.

Centaurs are in dynamic orbits, due to the gravity of their massive neighbor's. They act like a cross between a comet, and an asteroid. There is postulation that one of Saturn's moons may be a captured Centaur. A Centaur's orbit can be perturbed enough that it becomes a comet. They are named after shape-shifting creatures from mythology.

There are currently 97 known Trans-Neptunian Objects that have not been otherwise classified.

Wrap-up

It is interesting to read Willy Ley's book, “Gas Giants, the Largest Planets,” published posthumously in 1969. He traces the discoveries of Jupiter, Saturn, Uranus, and Neptune, Saturn's ring system, and their moons. Since then, the rings of Jupiter were discovered, as well as many more moons. We have sent spacecraft past all of these planets, and many of their moons.

At the time, all four were considered gas giants, but now we know that Uranus and Neptune as icy worlds. It s amazing, though, how much was known and surmised, with just ground-based telescopic observation.

Willy Ley was a pioneer of space travel. He worked with von Braun on rocketry, and was fascinated by all aspects of our solar system and beyond. I met him once, at a rocket launch, a most excellent and learned person.

He passed away on June 24, 1969, missing the first lunar landing

by the astronauts on July 20. He had figured out how to do it in the 1930's. It just took too long to implement his dream.

Glossary of Terms

Albedo – Whiteness, in Spanish; amount of sunlight reflected.

Anticyclonic – counter-clockwise rotation.

Apojove - the point furthest away from Jupiter by a body that orbits it.

Apsis – extreme point in an orbit.

ASIN – Amazon Standard Inventory Number.

Asteroid - minor planets, orbiting the Sun.

AU – astronomical unit, mean distance from the Earth to the Sun.

Bow shock- Where the solar wind begins to interact with a planet's magnetosphere.

CCSDS – Consultative Committee for Space Data Systems, standards organization.

Centaur – a minor planet in an unstable orbit, behaving like an asteroid or comet.

Comet – icy body orbiting the Sun in a very eccentric orbit.

DSN – Deep Space Net.

Ecliptic plane – the apparent path that the Sun seems to follow, the same as the Earth's orbit.

ESA – European Space Agency

Galilean Moons – the four moons spotted by Galileo – Io, Europa, Ganymede, Callisto

Gas giant – A large planet consisting mostly of hydrogen and helium.

Great Red Spot – a very large storm on Jupiter, larger than Earth.

Hippocamp – a Greek mythological creature, half horse, half fish.

HST – Hubble Space Telescope.

IAU – International Astronomical Union

Ice giant – A large icy/liquid planet, consisting of elements heavier than hydrogen and helium.

ISBN – International Standard Book Number.

JIRAM – Jovian Infrared Auroral Mapper, on the Juno spacecraft.

JOI – Jovian orbit insertion,

Jovian – pertaining to Jupiter.

JPL – Jet Propulsion Lab, operated by Cal Tech for NASA;

responsible for all deep space missions.

JSC – Johnson Space Center, Houston, Texas.

KBO – Kuiper Belt Object

Kuiper Belt – beyond Neptune, a ring of small icy asteroids and minor planets.

Lagrange (L) point – a null point in the gravity field in the 3-body program.

L1 - the Lagrange point between the 2 bodies.

L2 – the Lagrange point behind the smaller body.

L3 – the Lagrange point behind the larger body.

L4- the leading Lagrange in an orbit.

L5 – the trailing Lagrange point in an orbit.

LGM – little green men.

Magnetosphere – a space surrounding a planet or moon that is affected by the primary's magnetic field.

Magnetopause – abrupt boundary between a magnetosphere and the solar wind.

Magnetotail – magnetosphere extends away from the planet and the Sun.

MJS-77 circa 1977 mission to Mars, Jupiter, Saturn. Changed to Voyager.

Moon – object in orbit around a planet.

Mph – miles per hour

NASA - National Aeronautics and Space Administration.

NSF – (U.S.) National Science Foundation.

One-way light time – a measure of distance, in terms of how long it would take light to travel the distance.

Orbit – the path of one body around another, that are linked by gravity.

Planet – object in orbit around a star.

Perijove – the point in an orbit closest to Jupiter by an object that orbits it.

Ring system – a disk of solid material around a planet.

Roche's limit – withing 2.44 radii of the planet, no stable moon is possible, due to tidal forces from the primary.

RTG – Radioisotope Thermal Generator – electrical power plant

SOI – Saturn Orbit insertion; sphere of influence.

Solar flare – a sudden rapid emission of electrons, ions, and atoms from a star.

Solar System – A star and its associated planets and such.

Solar wind – stream of charged particles emitted from a star's upper atmosphere.

SNAP – Systems for Nuclear Auxiliary Power (RTG)

Tidal lock – where the same side of a object always faces the primary it is orbiting.

TNO – Trans-Neptunian objects.

Trojan - minor planet that shares an orbit with one of the larger planets.

VIM – Voyager Interstellar Mission.

Bibliography

Copernicus, Nicolaus *On the Revolutions of the Heavenly Spheres*, 1543, ASIN-B01MS8TGOV.

Fortescue, Peter and Stark, John *Spacecraft System Engineering*, 2nd ed, Wiley, 1995, ISBN 0-471-95220-6.

Irwin, Patrick G. J. *Giant Planets of Our Solar System: Atmospheres, Composition, and Structure*. 2003 Springer, ISBN-3-540-00681-8.

Ley, Willy *Gas Giants: The Largest Planets*, 1970, McGraw-Hill, ISBN-0070376387.

Nieto, Michael Martin *The Titus-Bode Law of Planetary Distances: Its History and Theory*, 1972, ISBN-1483126943.

Ross, Shane, “The Interplanetary Transport Network,” *American Scientist*, Vol 94, May-June 2006.

Jupiter

Bagenal, Fran; Dowling, Timothy E. *Jupiter: The Planet*,

Satellites and Magnetosphere, 2007, Cambridge University Press, ISBN-0521035457.

Fischer, Daniel, *Mission Jupiter: The Spectacular Journey of the Galileo Spacecraft*, 2001, ISBN-0387987649.

McAnallu, John W. *Jupiter: and How to Observe It*, ISBN-1852337508.

Sheehan, William; Hockey, Thomas *Jupiter*, 2018, ASIN-B07D3BBQ9Y.

Stakem, Patrick H.; Da Costa, Rodrigo Santos Valente; Rezende, Aryadne; Ravazzi, Andre “A Cubesat-based alternative for the Juno Mission to Jupiter,” 2017, Presentation to Flight Software-15, JHU-APL.

<https://solarsystem.nasa.gov/planets/Jupiter>

<http://nineplanets.org/Jupiter.html>

Saturn

Meltzer, Michael *The Cassini-Huygens Visit to Saturn: An Historic Mission to the Ringed Planet*, 2015, ISBN-3319076078.

NASA, *The Saturn System Through The Eyes Of Cassini*, 2018, ISBN-1680922149.

Regius, Codex *Enceladus - Iceland of Space: The Cassini spacecraft over the moon of chilly geysers*, 2017, ASIN-B078R3J1VZ.

Regius, Codex *Titan: Pluto's big brother: The Cassini-Huygens spacecraft and the darkest moon of Saturn*, 2016, ASIN-B01N5JBUSK.

<https://solarsystem.nasa.gov/planets/Saturn>

<http://nineplanets.org/saturn.html>

Uranus

Glaser, Chaya *Uranus: Cold and Blue*, ISBN-1627245677.

<https://solarsystem.nasa.gov/planets/uranus>

<http://nineplanets.org/uranus.html>

Neptune

Miner, Ellis D.; Wessen, Randii R. *Neptune: The Planet, Rings, and Satellites*, 2002, Springer, ASIN- B01A0CEX14.

<https://solarsystem.nasa.gov/planets/Neptune>

<http://nineplanets.org/neptune.html>

Resources

- New Horizons Mission -
https://www.nasa.gov/mission_pages/newhorizons/overview/index.html
- www.planetary.org
- <https://nssdc.gsfc.nasa.gov/planetary/planetfact.html>
- Wikipedia, various.
- New Horizons Mission -
https://www.nasa.gov/mission_pages/newhorizons/overview/index.html
- Visions and Voyages for Planetary Science in the Decade 2013 – 2022 (2011). avail:
<https://www.nap.edu/catalog/13117/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022>.
- JPL Small-body Database.

Avail:<https://ssd.jpl.nasa.gov/sbdb.cgi>

- <https://pds-rings.seti.org/jupiter/>
- <http://astronomy.swin.edu.au/cosmos/C/Centaurs>
- <https://svs.gsfc.nasa.gov/>
- <https://voyager.jpl.nasa.gov/mission/science/>
- <http://www.iflscience.com/space/how-saturns-shepherd-moons-herd-its-rings/>
- Wikipedia, various.

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Stakem, Patrick H. *The Architecture and Applications of the ARM Microprocessors*, 2013, PRRB Publishing, ISBN-1520215843.

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Stakem, Patrick H. *Architecture of Massively Parallel Microprocessor Systems*, 2011, PRRB Publishing, ISBN-1520250061.

Stakem, Patrick H. *Multicore Computer Architecture*, 2014,

PRRB Publishing, ISBN-1520241372.

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Stakem, Patrick H. *RISC Microprocessors, History and Overview*, 2013, PRRB Publishing, ISBN-1520216289.

Stakem, Patrick H. *Robots and Telerobots in Space Applications*, 2011, PRRB Publishing, ISBN-1520210361.

Stakem, Patrick H. *The Saturn Rocket and the Pegasus Missions, 1965*, 2013, PRRB Publishing, ISBN-1520209916.

Stakem, Patrick H. *Visiting the NASA Centers, and Locations of Historic Rockets & Spacecraft*, 2017, PRRB Publishing, ISBN-1549651205.

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Stakem, Patrick H. *Computer Architecture & Programming of the Intel x86 Family*, 2013, PRRB Publishing, ISBN-1520263724.

Stakem, Patrick H. *The Hardware and Software Architecture of the Transputer*, 2011, PRRB Publishing, ISBN-152020681X.

Stakem, Patrick H. *Mainframes, Computing on Big Iron*, 2015, PRRB Publishing, ISBN- 1520216459.

Stakem, Patrick H. *Spacecraft Control Centers*, 2015, PRRB Publishing, ISBN-1520200617.

Stakem, Patrick H. *Embedded in Space*, 2015, PRRB Publishing, ISBN-1520215916.

Stakem, Patrick H. *A Practitioner's Guide to RISC Microprocessor Architecture*, Wiley-Interscience, 1996, ISBN-0471130184.

Stakem, Patrick H. *Cubesat Engineering*, PRRB Publishing, 2017, ISBN-1520754019.

Stakem, Patrick H. *Cubesat Operations*, PRRB Publishing, 2017, ISBN-152076717X.

Stakem, Patrick H. *Interplanetary Cubesats*, PRRB Publishing, 2017, ISBN-1520766173 .

Stakem, Patrick H. Cubesat Constellations, Clusters, and Swarms, Stakem, PRRB Publishing, 2017, ISBN-1520767544.

Stakem, Patrick H. *Graphics Processing Units, an overview*, 2017, PRRB Publishing, ISBN-1520879695.

Stakem, Patrick H. *Intel Embedded and the Arduino-101*, 2017, PRRB Publishing, ISBN-1520879296.

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Stakem, Patrick H. *Exploration of the Gas Giants, Space Missions to Jupiter, Saturn, Uranus, and Neptune*, PRRB Publishing, 2018, ISBN-9781717814500.

Stakem, Patrick H. *Crewed Spacecraft*, 2017, PRRB Publishing, ISBN-1549992406.

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PRRB Publishing, ISBN-1549656619.

Stakem, Patrick H. *STEM-Sat, Using Cubesats in the pre-K to 12 Curricula, A Resource Guide for Educators*, 2017, ISBN-1549656376.

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Stakem, Patrick H. *Extreme Environment Embedded Systems*, 2017, PRRB Publishing, ISBN-1520215967.

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Stakem, Patrick H. *Lunar Orbital Platform-Gateway*, 2018, PRRB Publishing, ISBN-1980498628.

Stakem, Patrick H. *Space Weather*, 2018, ISBN-1723904023.

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1983196517.

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